(54) Analysis using Neutrons

(57) Apparatus for detecting the presence of a target element (eg Nitrogen) within an analysis region comprises neutron source(s) (not shown) and gamma ray detectors (D1 - D12). Counts accumulated for each detector are recorded and a best fit concentration profile computed on the basis of a selection of variables fewer in number than the number of gamma ray detectors used. The invention finds particular application in detecting the presence of explosives in luggage.

Fig.6.
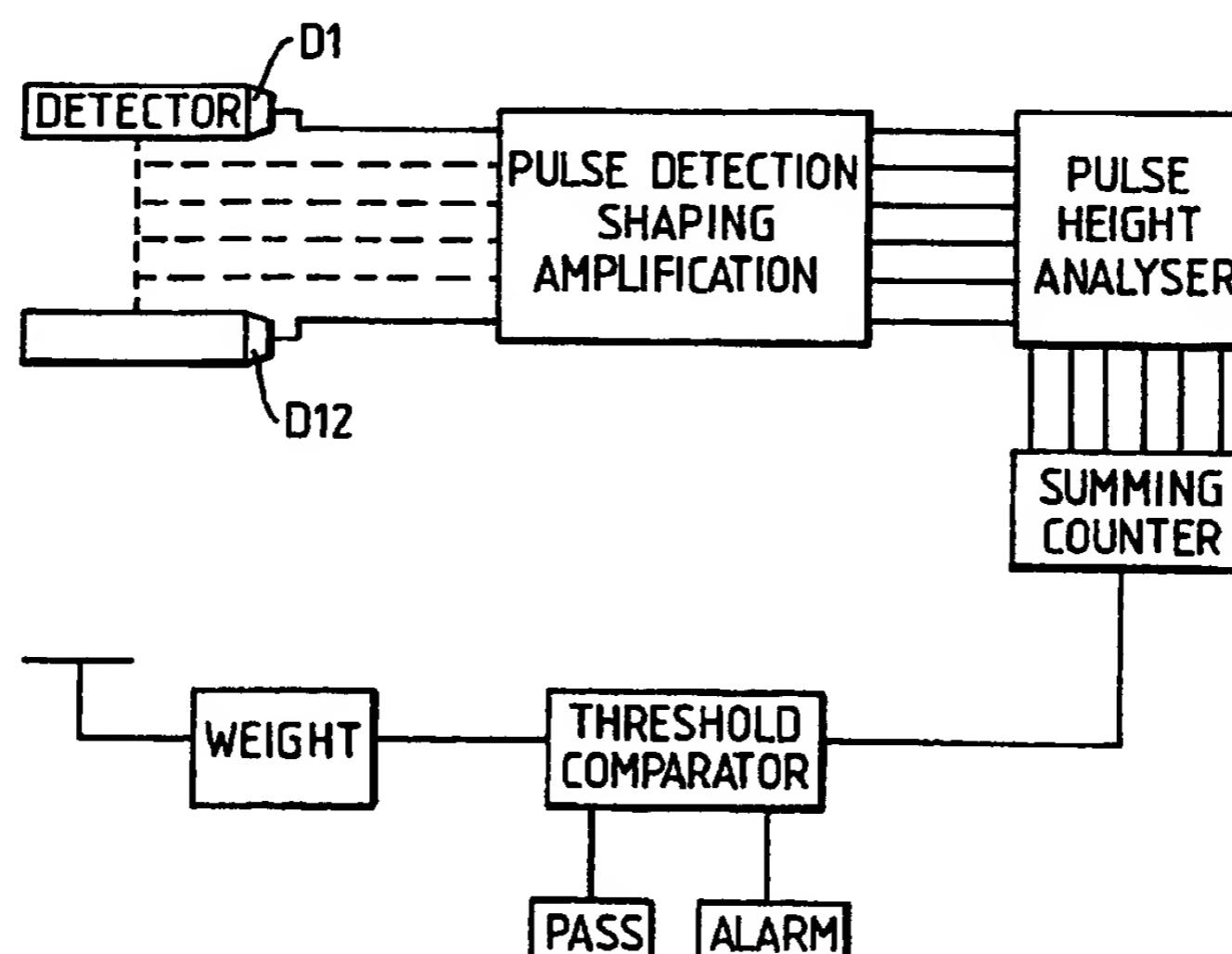
GB 2 274 708 A

Fig.1.

D7 — S3 — D8 — S4 — D9 — **11** — S1 — D1 — D2 — S2 — D3

12 — 13 — 14

Fig.2.

12 — D9 — S4 — D12 — **11** — D3 — S2 — D6

13 — 14

Fig.3.

12 — D1 — S1 — D2 — **11** — D5 — S2 — D3 — D6 — D4

13 — 14

Fig. 4.

60cm

32cm

90cm
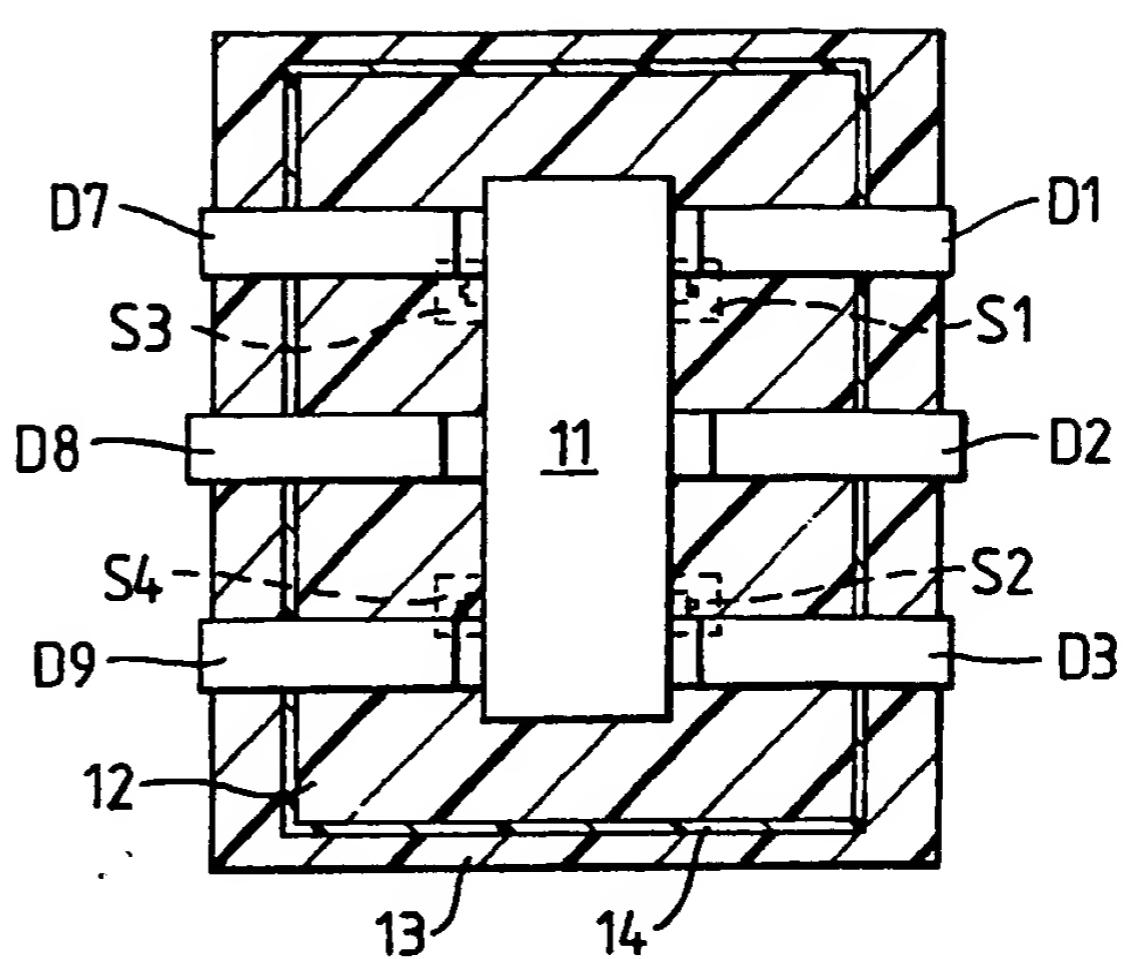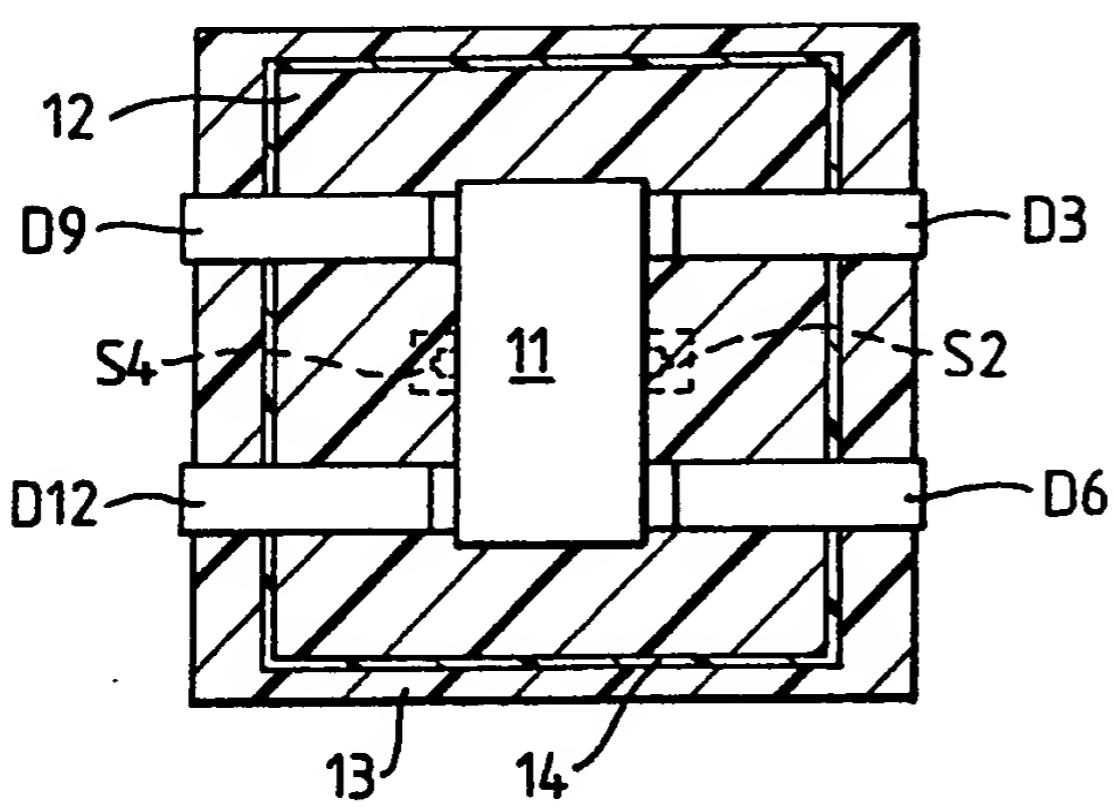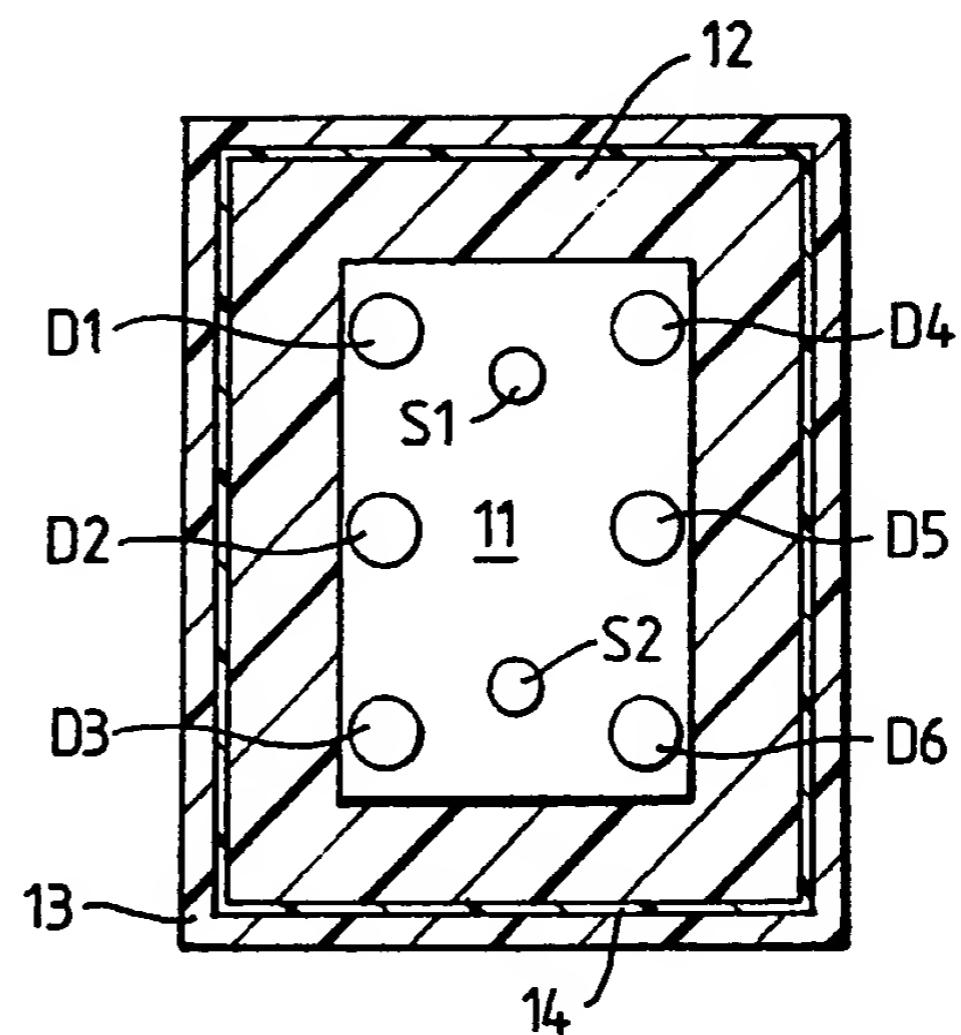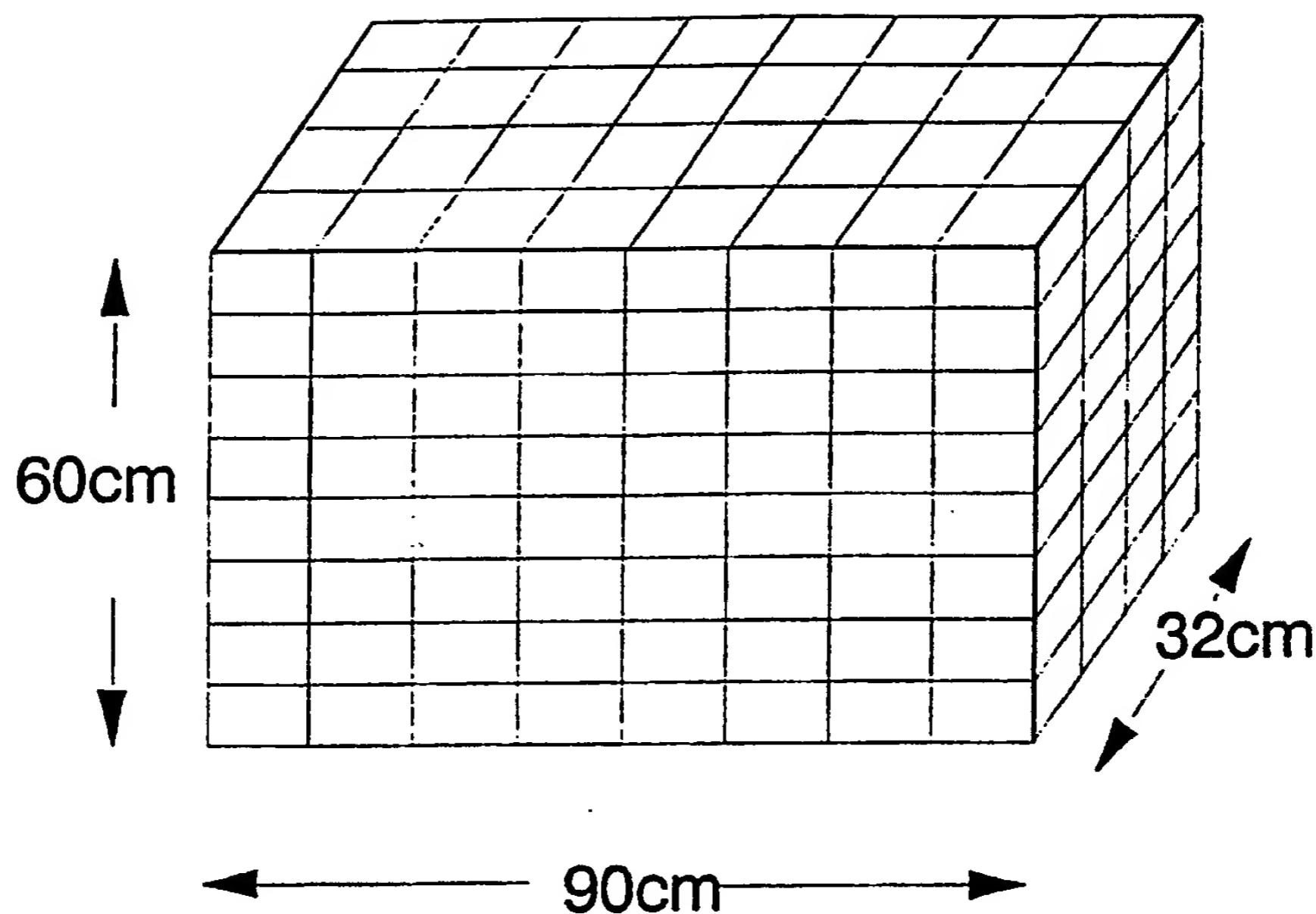
Detection Cavity

Fig. 5.
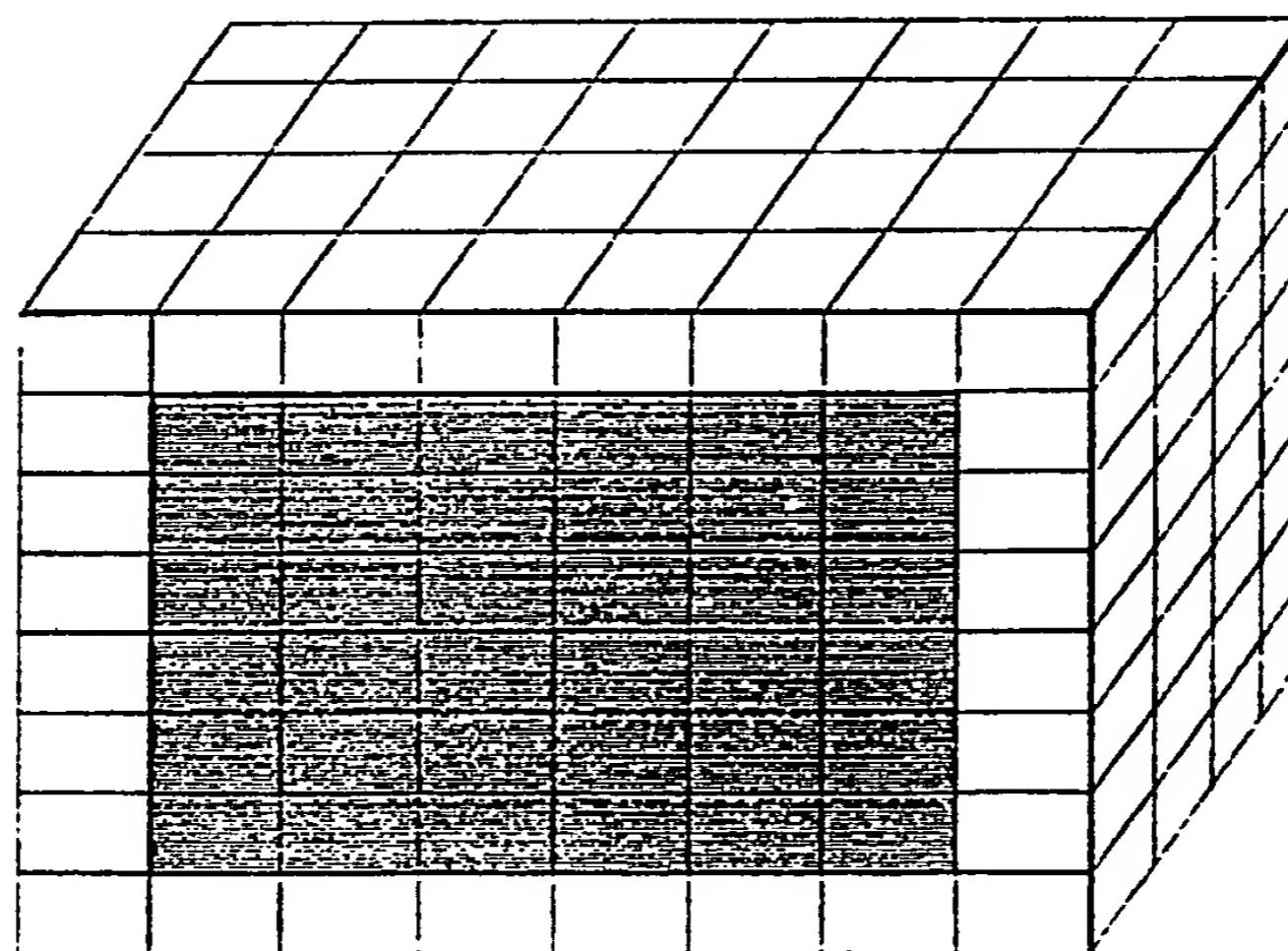

Suitcase Volume

Fig.6.
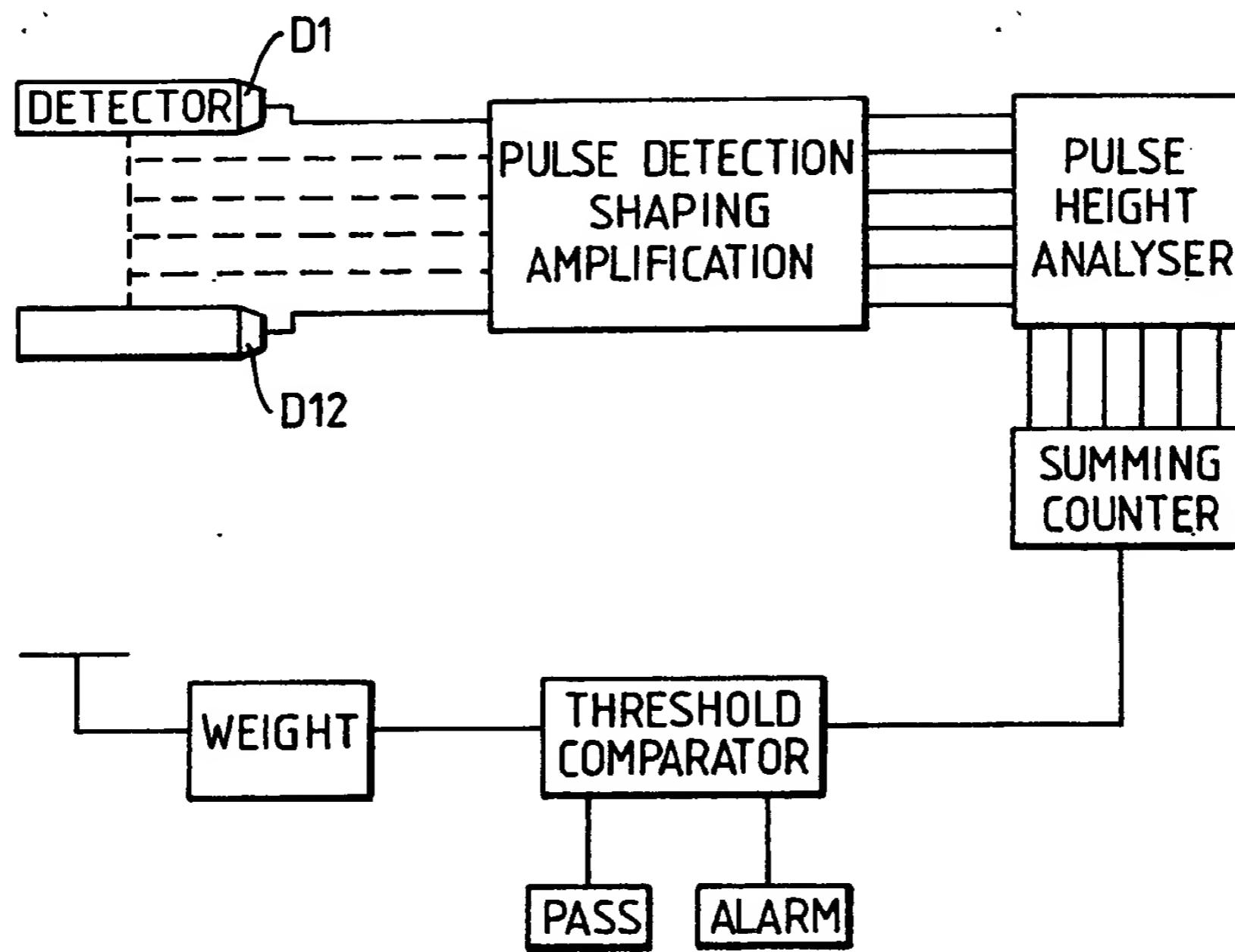
Analysis Using Neutrons

The invention relates to an apparatus for carrying out analysis using neutrons and in particular to an

5   apparatus for detecting the presence of a target element amongst material within an analysis region. An indication is provided in the event that the concentration of the target element exceeds a pre-determined level.

10

The apparatus finds application in the detection of explosives in luggage in, for example, an airport security system. For this, the analysis region is adapted to receive a container such as luggage, a package

15   or the like.

It is known that explosives generally contain a higher amount of nitrogen than normal objects to be found in luggage. There have been a number of proposals for

20   detecting explosives in luggage by apparatus which subjects the luggage to irradiation with neutrons and detects the emitted gamma rays which are characteristic of those emitted by nitrogen atoms which capture neutrons.

25

In, for example, GB 1 392 169 and GB 2 217 009, an imaging approach is adopted in which the configuration of neutron sources and detectors of gamma rays together with the output signal processing equipment are set up to

30   provide an indication of the spacial profile of nitrogen concentration within the item of luggage under examination. Relatively small regions exhibiting high nitrogen concentration are indicative of the presence of explosive within the luggage.

35

The problem with this approach is that, to secure

the necessary resolution for the imaging, a large number of detectors, a number of sources and/or long counting times are required. There are possibilities for trade-offs between these requirements. Thus it is possible to

5 compensate to some extent for a reduced number of detectors by increasing the counting times or to compensate for a reduced number of sources by increasing the number of detectors or the counting time, and so on. There are obviously practical limits and the pressure,

10 particularly for airport security systems, is for the counting time to be as short as possible whilst the number of sources and detectors needs to be kept to a minimum to reduce cost and, so far as sources are concerned, to minimise the radiation screening

15 requirements.

These problems are exacerbated by the difficulty in using detection of nitrogen for indicating the presence of explosive which arises because certain standard items

20 in luggage such as clothing, may have nitrogen contents which are not significantly less than the nitrogen content of the explosive.

GB patent specification 2 235 766 describes an

25 approach to these problems based upon an optimum source-detector distance and a symmetry in the source/detector array which enables meaningful results to be derived from the total sum of accumulated counts from all of the detectors.

30

With that arrangement, however, we have found that it remains difficult to reconcile the conflicting requirements of a reasonably low false alarm rate with a low rate of failure to detect presence of explosive.

35

Our patent specification number (Agents Ref: 14927

LgH) having the same filing date as the present
application describes a configuration of sources and
detectors, and a method of configuring the
source/detector array, which makes possible an
5   improvement in the resolution of these conflicting
requirements.

The present invention is based upon the appreciation
that further improvements towards the same objective can
10   be achieved by providing in the apparatus analysis means
for a particular form of processing of the counts of
detected gamma rays.

The invention provides apparatus for detecting the
15   presence of a target element amongst materials within an
analysis region and for providing an indication in the
event that the concentration of said element exceeds a
pre-determined level, the element being such as produces
a characteristic gamma ray when irradiated with neutrons,
20   which apparatus comprises an array of at least one source
of neutrons and a plurality of gamma ray detectors
positioned so that material in the analysis region is
subjected to irradiation with neutrons and the detectors
receive resultant gamma rays, analysis means comprising
25   means for accumulating counts at each detector
respectively of detected gamma rays having an energy
corresponding to that characteristic of the said element,
processing means for automatically processing the set of
accumulated counts from each detector to calculate a
30   concentration profile of the element across a plurality
of volume cells into which the analysis region is
notionally divided, which concentration profile is a
best fit for the accumulated count data, the calculation
being constrained to allow variation in a selection from
35   the large number of variables required to define the
location and element concentration level for each volume

cell, which selection comprises a number of variables less than the total number of detectors, and means, such as a display, an alarm, an indicator or a security mechanism, responsive to one or more features of the best

5   fit profile thus calculated.

       With this approach, it is possible notionally to divide the analysis region into a plurality of volume cells the number of which is greater, or very

10   substantially greater, than the number of detectors. The size of the volume cell is conveniently chosen to correspond with the typical size of object containing the target element which it is desired to detect.

15   When searching for a bomb in luggage, for example, the size of the volume cell is chosen to match the typical size expected for such a bomb.

       We have found that effective results are achieved

20   with an apparatus having twelve detectors if the selection of variables is based upon an assumed average concentration level in all but one volume cell, so that there are three variables for the best fit calculation, namely,

25

       1)   the location of the said one volume cell;

       2)   the element concentration level therein, and

30   3)   the magnitude of assumed average concentration level in all the other volume cells.

       It will be appreciated, however, that other selections may be chosen. For example, an apparatus having twelve

35   detectors would support a calculation involving more than three variables. The difficulties mount as the number of

variables is increased. It would be practicable for
example for the calculation to search for a best fit in
which there are five variables so as to allow for the
magnitude (3) of the assumed average element
5   concentration level in all the other volume cells to be
split into two. For this, the two volume cell groups
would have to be pre-defined, such as comprising the left
half and right half of the analysis region.

10   To provide for still further refinement of the
analysis if required, said analysis means comprises
further automatic processing means for comparing the
accumulated count for each detector with a mean count
pre-determined by a calibration for that detector in a
15   large sample of normal luggage, and for identifying the
detector for which the deviation from the said mean count
of the said accumulated count most exceeds the standard
deviation for that detector derived from the calibration
measurements in the sample of normal luggage.
20

According to a further aspect of the present
invention, operator controlled means is provided for pre-
selecting a specific volume cell within the analysis
region and for causing the said processing means to
25   compute the concentration level within the pre-selected
volume cell which, together with a calculated average
concentration level in all other volume cells, is a best
fit for the accumulated count data.

30   Where the analysis is to be applied to a container
such as luggage, a package or the like, the analysis
region is adapted to receive such container.

Preferably, the apparatus is combined with a
35   conventional X-ray apparatus for providing an X-ray image
of the container under examination. Conveniently this is

carried out at a closely positioned location and the
container moved from the X-ray apparatus to the neutron
interrogation apparatus. The operator controlling the
latter is provided at his console with a display of the
5   X-ray image which he can use, if desired, to provide to
the neutron interrogation apparatus the required input
for pre-selecting a specific volume cell identified from
the X-ray image as being suspicious.

10   A specific construction of apparatus embodying the
invention will now be described by way of example and
with reference to the drawings filed herewith in which:-

Figure 1 is a sectional plan view of an analysis
15   region of an apparatus for examination of suitcases,

Figure 2 is a sectional end view of the analysis
region,

20   Figure 3 is a sectional side view of the analysis
region,

Figure 4 shows diagrammatically a notional division
into volume cells of the analysis region of the apparatus
25   of Figures 1 to 3,

Figure 5 is similar to Figure 4 but shows the region
occupied by a standard size suitcase, and

30   Figure 6 is a diagrammatic representation in block
form of signal processing and display components.

The principle on which the apparatus operates using
thermal neutrons and the detection of 10.83 MeV nitrogen
35   gamma rays arising from the $^{14}N(n,\gamma)$ reaction is known and
described, for example, in GB 2 235 766. The drawings

filed herewith and the following description have
therefore been limited to the essential parts of the
apparatus which are key to understanding and putting into
effect the present invention.

5

Referring to Figures 1 to 3, the analysis region is
provided by a detection cavity 11 on each side of which
is an array of ^{252}Cf neutron sources S1, S2, S3, S4 and
sodium iodide gamma ray scintillation detectors D1, D2,
10 D3, D4, D5, D6, D7, D8, D9, D10, D11, D12. Detectors D10
and D11 are not visible in Figures 1 to 3, being obscured
by other detectors. The cavity is surrounded by graphite
or low density polythene 12, which acts as a moderator
and assists to some extent in the processes by which fast
15 neutrons emitted by the source are thermalised and become
available within the cavity 11 for capture reactions.
Cylindrical recesses within the graphite or low density
polythene 12 are provided to receive the sources S1..S4
and detectors D1..D12. The recesses containing the
20 sources are lined with a cylindrical lead cap to shield
the detectors from gamma rays emitted by the source. The
recesses for the detectors are lined with boron sheet to
limit the direct passage of neutrons from the sources
into the detectors in which reactions may otherwise occur
25 and interfere with the desired detection of gamma rays
emanating from the cavity 11.

An outer layer of biological shielding is provided
by boron loaded polythene internally lined with a layer
30 of low density polythene, referenced respectively 13 and
14.

The significance and characteristics of the
source/detector arrays as shown are discussed in more
35 detail in our co-pending application No. (Agents Ref:
14927 LgH) filed on the same day as the present

application.

Figure 4 illustrates how the detection cavity which, in this example, has dimensions 90 cm x 60 cm x 32 cm, is
5   notionally divided into 256 volume cells forming an 8 x 8 x 4 array. Figure 5 shows by shading the region of 6 x 6 x 4 of these cells occupied by a typical standard suitcase.

10   As illustrated in Figure 6, signals from the detectors D1...D12 are detected and processed in a conventional manner and counts accumulated for each detector for events corresponding to nitrogen gamma rays. Position sensors provide an indication of the size and
15   location of luggage positioned in the cavity 11. The detector/count data and position data are fed to a computer in which analysis is performed as described below and an appropriate operator display generated.

20   Our co-pending application No. (Agents Reference 14927 LgH) describes how the apparatus is well adapted for operation with the simplest form of analysis in which the sum of counts from all 12 detectors is used as the measurement value. The method requires neither
25   correction for background in the detectors nor information about the position and dimensions of the suitcase. The method is robust and relatively insensitive to reductions in counting period. However, the total count method is limited by the inability to
30   distinguish between a small region of high nitrogen density (as in an explosive) and a large region of lower nitrogen density (as may be present in clothing).

To overcome this limitation, data from the
35   detectors, coupled with information which identifies the location and dimensions of the suitcase under

examination, are analysed in a way which provides a degree of "nitrogen imaging" whilst avoiding the need to invoke the highly complex procedures and equipment required for conventional image analysis. In particular,

5 it is possible to produce an approximated image at an apparent resolution corresponding to notional division of the suitcase into a number of volume cells which very substantially exceeds the number of detectors. In this example there are 256 volume cells and 12 detectors, the

10 volume cell dimensions being chosen to correspond to the anticipated dimensions of a typical bomb.

In accordance with this method, the assumption is made that there is a fixed, relatively low, level of

15 nitrogen concentration in all of the notional volume cells within the suitcase except one in which it is assumed there is a higher level of nitrogen concentration due to the presence of explosive material in that volume cell.

20

On the basis of these assumptions, the count in any one of the detectors will be the sum of the counts expected at that detector due to a uniform nitrogen concentration level in each volume cell together with the

25 background and the count due to the one volume cell containing the higher concentration level of nitrogen. This model has three variables namely the uniform concentration level of nitrogen, the concentration level of nitrogen in the volume cell containing explosive and

30 the location of the latter volume cell.

The analytical approach is to discover values for these three unknowns which best fit the matrix of detector/count information provided by the apparatus.

35 Having reduced the analysis to this form, it is a relatively straightforward and conventional matter to

programme the computer to discover the best fit solution. The requirement is to find values of the three unknowns which result in a minimum in the sum for all detectors of the difference between the measured detector count and the count predicted for that detector by the selected values of the three unknowns in the model. Expressed mathematically, the objective is to minimise V where

$$V = \sum_j (D_j^{measured} - D_j^{model})^2$$

. The approach is to programme the computer to execute a standard least squares fit for the two nitrogen concentration unknowns for each volume cell location. The best fit is then chosen by selecting the location of volume cell which minimises V subject to this corresponding with a positive value of nitrogen concentration in the volume cell suspected of containing explosive.

It will be appreciated that, in using this method, a cell will be identified as containing an excess nitrogen concentration level even although the suitcase does not contain any explosive. This is because the assumption of uniform distribution of nitrogen is not an accurate representation of a normal suitcase. However, if explosive is present, this analytical approach will generate a larger distinction between a suitcase containing explosive from one which does not than the total count approach. A threshold level can thus be set for triggering alarm and the alarm trigger displayed to the operator can include an indication of the volume cell within the suitcase where the explosive is suspected.

This analytical approach thus provides a significant advance on the total count approach, but has the

additional advantage that it is capable of providing a
very significant advance in detection efficiency if the
system is combined with an X-ray detection system.

5   Arrangements for providing more than one type of
analysis of luggage have been described as, for example,
in GB 2 217 009. However, the approach there was to use
the neutron analysis equipment for a preliminary screen
and to pass on to X-ray analysis those items of luggage
10   which appeared suspect from the neutron analysis.

If this approach is reversed and an X-ray image
taken first, then an operator may determine from the X-
ray image that a particular region of the suitcase is
15   suspect. The operator can input information as to the
location of this volume cell to the computer, whereupon
it is possible to carry out the least squares fit for
only two variables, the location of the volume cell now
being fixed. As a consequence, the estimate from the
20   analysis of the level of nitrogen concentration in the
suspect volume cell, if explosive is present in that
cell, will be much more accurate so that detection limits
are very significantly improved.

25   Where it is not possible or practicable to provide
operator information as to the location of a suspect
volume cell, a further analysis technique may be employed
as an adjunct to that described above.

30   This further analysis technique, referred to as the
most anomalous detector technique, relies upon the fact
that explosive near a detector is likely to give a much
more anomalous reading for that detector than for the
other detectors.
35

For this approach, the computer is programmed to

calculate the difference between the count in each
detector from the average over all detectors and indicate
the maximum value of this difference. However, in order
to provide a sensible threshold for triggering an alarm,

5   it is necessary to refine the approach somewhat and
provide a calibration. Accordingly, data from a large
set of examinations of "normal" luggage containing no
explosive is used to derive a mean detector count D_j^{mean}
for each detector, together with the corresponding

10   standard deviations σ_j^D. The computer is then programmed
to derive a value A where

$$A = \max\left(\frac{D_j^{measured} - D_j^{means}}{\sigma_j^D}\right) j = 1 \ldots 12$$

15

Once again, with this form of analysis, the results
are very sensitive to changes in source size and counting
20   times. Corrections also have to be applied for suitcase
position and dimensions.

The invention is not restricted to the details of
the foregoing examples. Thus, in the example the best
25   fit calculation is based upon three variables. With
twelve detectors it is possible to allow for more
variables, in theory up to any number less than twelve,
in practice, the number of variables allowed in the best
fit calculation should be less than about one-half,
30   preferably one-quarter of the number of detectors.

Reference is made to the use of low density
polythene for moderation and biological shielding
purposes. High density polythene can be used instead,
35   and with advantage, provided care is taken to ensure that
the material used does not contain excessive voids.

Whilst apparatus for detecting nitrogen
concentration is described for checking luggage for
presence of explosive material, it will be appreciated
that the apparatus is adaptable for other applications,
5   such as sorting material streams, e.g. ores, where there
is a requirement to identify the location of a component
or region having a concentration of the target element
above a pre-determined limit.

10

Claims

1. Apparatus for detecting the presence of a target element amongst materials within an analysis region and for providing an indication in the event that the concentration of said element exceeds a pre-determined level, the element being such as produces a characteristic gamma ray when irradiated with neutrons, which apparatus comprises an array of at least one source of neutrons and a plurality of gamma ray detectors positioned so that material in the analysis region is subjected to irradiation with neutrons and the detectors receive resultant gamma rays, analysis means comprising means for accumulating counts at each detector respectively of detected gamma rays having an energy corresponding to that characteristic of the said element, processing means for automatically processing the set of accumulated counts from each detector to calculate a concentration profile of the element across a plurality of volume cells into which the analysis region is notionally divided, which concentration profile is a best fit for the accumulated count data, the calculation being constrained to allow variation in a selection from the large number of variables required to define the location and element concentration level for each volume cell, which selection comprises a number of variables less than the total number of detectors, and means; such as a display, an alarm, an indicator or a security mechanism, responsive to one or more features of the best fit profile thus calculated.

2. Apparatus as claimed in Claim 1 in which the said processing means is arranged notionally to divide the analysis region into a plurality of volume cells the number of which is greater than the number of detectors.

3.   Apparatus as claimed in Claim 2 in which the said
number is such that the size of each volume cell
corresponds with the size of object containing the target
element which it is desired to detect.

5

4.   Apparatus as claimed in Claim 3 for searching for a
bomb in luggage in which the said number is such that the
size of the volume cell corresponds to the typical size
expected for a bomb concealed in luggage.

10

5.   Apparatus as claimed in any of the preceding claims
in which the said selection comprises a number of
variables less than half the total number of detectors.

15   6.   Apparatus as claimed in Claim 5 in which there are
more than six detectors and the selection of variables is
based upon an assumed average concentration level in all
but one volume cell, so that there are three variables
for the best fit calculation comprising respectively the
20   location of the said one volume cell, the element
concentration level therein, and the magnitude of assumed
average concentration level in all the other volume
cells.

25   7.   Apparatus as claimed in Claim 6 in which there are
twelve or more detectors.

8.   Apparatus as claimed in any one of the preceding
Claims in which said analysis means comprises further
30   automatic processing means for comparing the accumulated
count for each detector with a mean count pre-determined
by a calibration for that detector in a large sample of
normal luggage, and for identifying the detector for
which the deviation from the said mean count of the said
35   accumulated count most exceeds the standard deviation for
that detector derived from the calibration measurements

in the sample of normal luggage.

9.   Apparatus as claimed in any one of the preceding Claims in which operator controlled means is provided for pre-selecting a specific volume cell within the analysis region and for causing the said processing means to compute the concentration level within the pre-selected volume cell which, together with a calculated average concentration level in all other volume cells, is a best fit for the accumulated count data.

10.   Apparatus as claimed in any one of the preceding Claims in which the analysis region is such as to receive luggage or packages typical of those used by travellers.

11.   Apparatus as claimed in any one of the preceding Claims combined with a conventional X-ray apparatus for providing an X-ray image of an article under examination.

12.   Apparatus as claimed in Claim 11 in which a display console is positioned and connected so as to provide an operator with an X-ray image which he can use when controlling the analysis means of the neutron interrogation apparatus.

13.   Apparatus substantially as hereinbefore described with reference to, and illustrated in, the drawings filed herewith.

Patents Act 1977
Examiner's report to the Comptroller under Section 17
(e Search report)

Relevant Technical Fields	
(i) UK Cl (Ed.M)	G1A (AMHR)
(ii) Int Cl (Ed.)	G01N; G01V

Search Examiner
S J MORGAN

Date of completion of Search
29 MARCH 1994

Databases (see below)
(i) UK Patent Office collections of GB, EP, WO and US patent specifications.

(ii) ONLINE DATABASE: WPI

Documents considered relevant following a search in respect of Claims :-
1-12

Categories of documents

X: Document indicating lack of novelty or of inventive step.

Y: Document indicating lack of inventive step if combined with one or more other documents of the same category.

A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages	Relevant to claim(s)
A	WO 92/12415 A1 (GENERAL RESEARCH CORP) See lines 1-10, page 20 in particular	1